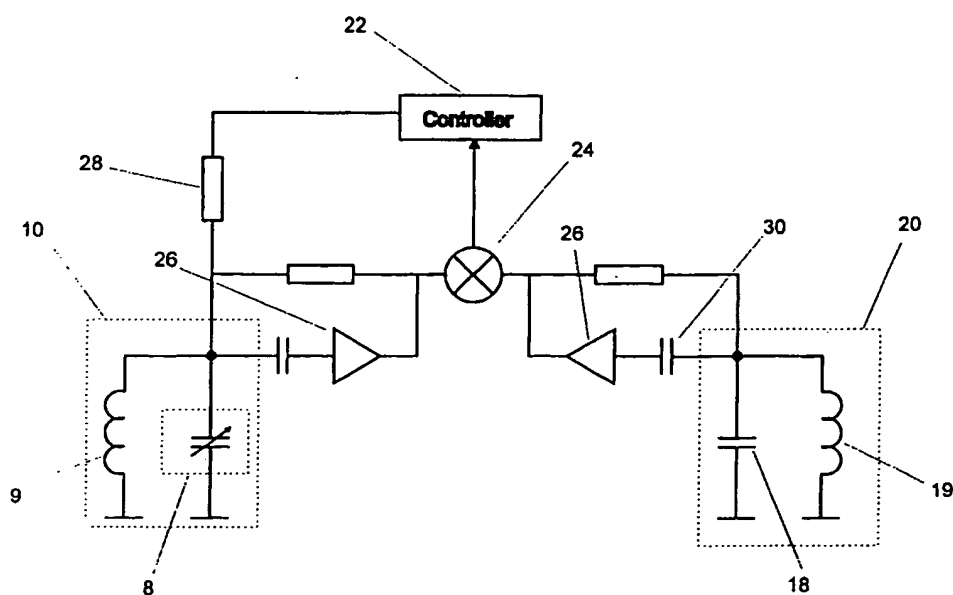


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(54) Title: METHOD, APPARATUS AND ARRANGEMENT FOR DETERMINATION OF RADIATION



(57) Abstract

The present invention relates to a method according to which a radiation detector (8) is connected as a part of an oscillating circuit (10) for determining the radiation from the capacitance change induced by radiation to the capacitance of the detector. An apparatus for determining the radiation consists of a radiation sensitive oscillating circuit (10), which includes a radiation detector component (8) and a resonator component (11) or alternatively an inductor component (9). An arrangement according to the invention includes a radiation sensitive oscillating circuit (10) and also a reference oscillating circuit (20), which includes a reference capacitance (18) and a resonator component or an inductor component (19) corresponding to the structure of the radiation sensitive circuit (10).

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METHOD, APPARATUS AND ARRANGEMENT FOR DETERMINATION OF RADIATION

Field of the invention

The present invention relates to the determination of radiation, such as electromagnetic or particle radiation, to be used for instance in applications determining the energy of the radiation, and more particularly to a method in accordance with the preamble of claim 1. The invention relates also to an apparatus for determining radiation in accordance with the preamble of claim 7 and to an arrangement for determining the radiation in accordance with the preamble of claim 13.

Background of the invention

Up to the present days the most common way of measuring radiation, such as ultraviolet, X-ray, gamma-ray and particle radiation, has been to measure the radiation induced charge inside a semiconductor material. This charge has been input to a charge sensitive preamplifier, which has converted the charge signal to a voltage signal, which in turn can be converted to define the energy of the radiation in a desired scale. This known solution has, however, several disadvantages: for example, it is often very difficult to make measurements, which have an adequate accuracy, for instance because of excessive electrical noise caused by the preamplifier and the conduits. In some cases the response of the amplifying circuitry is not fully linear, and therefore complicated calibration and correction factors and circuitry is required. Furthermore, in the presently known solutions the electrical noise is dependent on the capacitance of the detector, which limits the size of the detector (the active detection area). For example, for a 0.5 mm thick semiconductor crystal, the upper limit for the active detection area is considered to be

10 mm², after which the electrical noise starts increasing considerably in respect with the size of the detector. However, in order to get fast and accurate measurements it would be advantageous to have as large semiconductor crystals as possible.

In order to get rid of the disadvantages of the prior art detector systems, it has been proposed, for instance, that it is possible to measure the change in the capacitance of the detector instead of measuring the radiation induced charge pulse of the semiconductor detector with a charge sensitive amplifier. This change is caused by the charge pulse inside the detector.

US patent number 3,745,357 (Been) discloses a solution in which the determination of radiation is done by using a capacitive bridge in order to circumvent the electrical noise, which is present when using charge sensitive preamplifiers. However, this method has been introduced mainly for a continuous measurement of the intensity of the radiation, and it's sensitivity for a measurement of the energy of individual radiation photon or particle has not been adequate. The method has been realized by using components, which do not correspond the state-of-art technology. Therefore it has not gained any notable success in the field of radiation detection.

Another method, which is based on the measurement of the capacitance of the detector, is presented in US patent 5,336,890 (Kitaguchi et al). There both the top and the bottom surfaces of the detector crystal have pn-junctions, onto which a reverse bias voltage is applied. Both of the pn-junctions act as cathode (or anode) electrodes simultaneously, and they give a signal to a read-out circuitry, after which the signal is analysed by additional circuitry, which uses the information from both of the electrodes. The sensitivity of this solution, however, is not adequate for the measurement of eg. individual X-ray photons. It's read-out electronic is not

considered sensitive, and the realization of the detector-electronics system is complicated. The solution, in general, has not shown to be practical, and has thus not gained any remarkable success.

Summary of the invention

It is an object of the present invention to remove the disadvantages of the prior art and provide a completely new solution for measuring/detecting radiation, which is based on the determination of the capacitance differences caused by the radiation.

It is also an object of the invention to provide a method and an apparatus, by means of which the measurement/detection of radiation can be made reliably and accurate with semiconductor technology.

It is a further object of the invention to provide a method and an apparatus, with which the detection area of the detector component can be increased without any undesirable effects to the accuracy of the measurement.

Furthermore, an object of the invention is to provide a method and an apparatus, by means of which the reliability, accuracy and usability can be increased.

The invention is based on the realization that a signal from a radiation detector can be read with a completely novel way by means of a particular resonating ie. oscillating circuit, wherein said signal is based on the determined change in the capacitance of the detector component, said change being induced by the radiation. At least one resonating ie. oscillating circuit is provided as a part of the inventive apparatus. This oscillating circuit makes it possible to transform the change in the capacitance into a signal that corresponds the energy and intensity of the radiation. The used circuit may

comprise a piezoelectric, dielectric or other type of resonator or an inductor.

More precisely, the inventive method is characterized by what is presented in the appended claims 1...6 and in particular in the characterizing portion of claim 1. The apparatus in accordance with the invention is mainly characterized by what is presented in the appended claims 7...12 and in particular in the characterizing portion of claim 7. The arrangement in accordance with the invention is mainly characterized by what is presented in the appended claims 13...15 and in particular in the characterizing portion of claim 13.

In a preferred embodiment of the invention, the method for the determination of radiation comprises a step for connecting the radiation detector component as a part of the radiation sensitive resonating ie. oscillating circuit means in order to measure the capacitance change induced by the radiation.

According to an embodiment of the invention, the capacitance change can be determined by measuring the change in the amplitude, phase or frequency of the radiation sensitive resonating or oscillating circuit. The determination of the radiation can be performed by connecting a reference oscillating circuit, which will not become exposed to the radiation, in parallel with the radiation sensitive circuit.

The apparatus in accordance with the invention comprises an oscillating circuit, which includes the detector component and a resonator or alternatively an inductor component, said oscillating circuit being arranged to detect the radiation induced change in the capacitance of the detector component.

According to an embodiment of the invention, the apparatus can comprise means for measuring the phase, amplitude or frequency of the oscillating circuit. The radiation sensitive detector means can consist of a semiconductor material.

An arrangement in accordance with the invention for determining radiation comprises an oscillating circuit, which includes a resonator or alternatively an inductor component, while the oscillating circuit is arranged to detect the radiation induced change in the capacitance of the detector component. The arrangement comprises further a reference oscillating circuit, which includes a reference capacitance and a resonator or an inductor component corresponding with the structure of the radiation sensitive circuit.

The apparatus and the method in accordance with the invention can be used in all applications which require a determination of radiation, and especially the energy of radiation. At the present, the commercially most important fields of utilization, without any restriction to these, are considered to be the equipment which are used in the field of energy dispersive spectroscopy of ionizing radiation. Such equipment can be, for example

X-ray spectrometers:

Laboratory analysis equipment, process control and analyzing equipment in industry, such as in the paper or chemical industry (eg. analysing of coatings), industrial x-ray analysis equipment, field instruments for on-site elemental analysis and equipment for X-ray microanalysis, x-ray astronomy or the research of X-ray physics, solid state physics and materials science.

Gamma-ray spectroscopy:

Determination of radioactive isotopes, radiation monitoring systems in nuclear power plants etc. or nuclear spectroscopy.

UV-spectroscopy:

VUV spectroscopy for materials research.

The invention offers considerable advantages. It enables an improved detection and/or measurement or determination of

radiation with semiconductor technology. The active detection area of the detector component can be increased without undesirable effects to the accuracy of the measurements. The measurements can be made faster and more accurate and yet keep the needed apparatus simple and compact. The apparatus can be constructed from known standard components, such as the silicon components used in microelectronics industry. Correspondingly it is possible to use the standard manufacturing techniques already used in microelectronics industry, which lowers the manufacturing costs of the detecting apparatus. Advantageously, the apparatus, operating in accordance with the invention can operate in room temperature or close to room temperature using at most a lightweight thermoelectric cooler, which is an improvement in comparison with the prior art semiconductor detectors, which use, for instance, heavy liquid nitrogen cooling.

The invention and the other objects and advantages thereof are described in the following with examples and referring, at the same time, to the enclosed drawing, in which the similar numbers in various figures refer to the corresponding features. It will be understood, that the changes and modifications may be made to the invention by those skilled in the art without departing from the spirit and scope of the invention as set forth in the claims appended hereto.

Brief description of the drawing

Figure 1 shows a circuit diagram of one embodiment according to the present invention.

Figure 2 shows a possible oscillating circuit.

Figures 3 - 5 show schematic cross-sections of possible semiconductor detector structures.

Figure 6 shows an example of a detector apparatus in accordance with the invention.

Detailed description of the drawing

Figure 1 shows an embodiment of a radiation detection arrangement in accordance with the invention. It consists of a radiation sensitive oscillating circuit 10, and a reference oscillating circuit 20 connected parallel with the oscillating circuit 10. Depending on the application, the circuitry further comprises control or read-out electronics, which in the examples consists of a control circuit 22, mixer circuit means 24, preamplifiers 25 and 26, resistors 28 and capacitors 30.

The radiation sensitive circuit 10 consists of an inductor 9 and a radiation detector 8. Correspondingly the reference oscillating circuit consists of an inductor 19 and a reference capacitor 18, the values of which are known. The reference circuit 20 is constructed eg. by means of a suitable isolation such that it will not receive any radiation, ie. it is not exposed to the radiation. The possible structures of the radiation detector 8 are described in more detail in connection with figures 3-5.

As disclosed by figure 2, the inductor 9 in figure 1 can be replaced with a piezoelectric resonator 11. In addition, a dielectric resonator or some another type of a resonator component used in radio frequency and/or microwave electronics can be used. When using the piezoelectric resonator 11 a similar reference piezoelectric resonator will be used instead of the reference inductor 19 of figure 1. By using an inductor it is possible to achieve higher frequencies for operating the circuitry and to use compact components at the same time. However, the circuits which are based on resonator components are usually more stable in respect with temperature variations.

Before going into the details of the embodiment of the inven-

tive arrangement, the structures of the radiation detector components are explained with reference to figures 3-5.

In figure 3 the detector structure embodies a single side processed pn-junction diode 8. The diode 8 comprises a metallization 7 on the surfaces thereof according to the figure 3, n-type silicon substrate 6 within the structure and p+ and n+ contacts (electrodes), which may in most cases be ion implanted on the substrate. Furthermore figure 3 shows the passivation regions 3. The depletion region 14 of the diode 8 is achieved by depleting the n-substrate from charge carriers with an electric field.

In principle, the semiconductor substrate 6 can be of any semiconductor material, onto which it is possible to pattern pn-junctions, and which can be depleted from charge carriers with an electric field. One material, which is considered very good because of the desirable properties and manufacturing technology, is high purity silicon (resistivity > 1000 Ωcm). The commercial availability of this exemplifying material is also good. Other possible materials are, for example, gallium-arsenide (GaAs), cadmiumtelluride (CdTe), cadmium-zinc-telluride (CdZnTe) or germanium (Ge), or other corresponding materials per se known by the skilled person.

The charge accumulated into the diode 8 needs to be reset from time to time by using a suitable switch, such as the switching circuit 16. In figure 3 the other end of the diode 1 is shown as just connected to a power supply in order to charge the capacitor C_S . During the measurement, the power supply is connected off and the charge, which is induced by the radiation, is changing the bias voltage according to the equation

$$\Delta V = C_S \cdot \Delta Q,$$

wherein ΔV is the change in the voltage, C_S is the capacitance of the capacitor and ΔQ is the change of the charge which was induced by the radiation.

The change of the voltage is dependent on the square root of the thickness D of the depletion region 14, which in turn is inversely dependent to the capacitance C_d of the detector.

When using eg. a diode with an active detection area of 25 mm^2 , it is possible to design a circuitry, where the relative capacitance change $\Delta C/C_d$ (relative to the capacitance of the detector 8 of figure 3) caused by one electron is of the order of 10^{-10} . The relative changes of the capacitance with this magnitude can be measured accurately by the arrangement constructed in accordance with the invention, in which the detector 8 is connected as a part of an oscillating circuit 10.

The detector 8, shown in the figure 3, the capacitance of which changes as a result of the radiation induced charge, is advantageous particularly because it's structure is simple and it is therefore affordable to manufacture. All the required components and manufacturing techniques are per se known, and their availability is good.

Figure 4 presents a double-side processed capacitive radiation detector 8. The operation thereof is based on the fact that the electrons (-) are drifted with an electric field into the centre of the detector and the holes (+) are collected onto the surface electrodes 5 on a detector chip. The detector needs to be reset from time to time in order to clear the substrate 6 from the accumulated electrons.

With the detector structure of figure 4, the capacitance change is not measured by measuring the change in the depletion region, but by measuring directly the change of the capacitance which is caused by the radiation induced charge. Thus the additional capacitor C_s shown in figure 3 is not needed in here. With the detector structure of figure 4 it is possible to achieve a better sensitivity than with the detec-

tor structure of the figure 3. In theory it is possible to acquire a value $\Delta C_d/C_d = 10^{-8}$ for a detector with an active area of 25 mm². The fact that the utilization of this structure requires relatively complicated circuitry for biasing the detector chip can be regarded as a disadvantage compared with the structure of figure 3. Also the design and manufacture of the structure which can be processed from the two sides requires more time and effort and hence it is more expensive. At the present the manufacturing of the structure of figure 4 is considered to be twice as expensive as that of the structure of figure 3.

The figure 5 shows still another detector structure, which is based on the direct measurement of the charge cloud. In this detector structure the electric field is formed and influenced by the metal contacts 7 grown over the passivation layer 3 on the surfaces of the semiconductor substrate. In this case, the previously mentioned pn-junctions 3 or 4 are not needed, which makes the manufacturing of the detector easier and cheaper. A potential problem may be that the electrical field can not penetrate into the detector substrate as result of the thin charge carrier layers, accumulated directly under the surface passivations. These accumulation layers may screen the electric field so that no depletion layer is formed and the radiation induced charge is not seen by the electronics. However, the operation of this structure relies on the fact that there are parasitic currents from the accumulation layer to the surface electrodes, which correspond to the existence of a very high value resistor (> 100 GΩ). Another possibility to circumvent this problem is to add a resistive contact to the substrate somewhere on the detector area.

The radiation induced signal, created inside the radiation detector 8, such as the example structures described above, can be measured in a completely novel way. In general, the operation of the radiation detector 8 is based on the fact that the radiation caused by an individual radiation quantum

(photon or particle) induces a number of charge carriers into the depletion area 14 of the detector, said number corresponding the energy of the quanta. As was explained above, the depletion region 14 of a semiconductor is depleted from charge carriers by means of the electric field. The radiation induces a change in the capacitance of the detector 8, and this change is then measured according to the invention.

Sensors, the operation of which is based on the measurement of the change in the capacitance, have been used previously, for example, in the measurement of temperature, humidity, velocity, acceleration, angular velocity, angular acceleration etc. In this invention the sensor arrangements of the above mentioned kind have been utilized for the first time in the measurement of radiation so that the detector can be realized with semiconductor technology. This enables the manufacture of sensors, which are more effective and accurate, but still cheaper and easier to manufacture and which can therefore be more easily mass produced in comparison with the prior art gas filled technology or liquid nitrogen cooled detectors.

The radiation induced change in the capacitance of a radiation detector can be measured eg. by connecting the detector as a part of such an oscillating circuit which is driven by an oscillator, and monitoring the change of the frequency, amplitude or phase of this circuit. At present, the method, where the capacitance of the detector is tuned into a resonance with an inductor or a resonator component, and the change in the impedance is measured with a phase sensitive amplifier is considered as the most accurate. In order to widen the dynamics it may be advantageous to use a tuned bridge connection. The resolution can be further optimized by adapting the optimum of the noise impedance of the preamplifier to equal with the tuned oscillating circuit output impedance.

Alternatively, analogous to the previous method, the radiation detector can be connected to form a part of an oscillator

circuit, in which case the radiation induced change in the capacitance of the detector can be monitored by measuring the change of the frequency, amplitude or phase of this oscillator circuit.

According to a preferable readout technique, which can be implemented in accordance with the invention, the change on the capacitance of the detector 8 is measured so that the detector structure 8 is connected in parallel with an inductor 9 or a resonator component 11 such as a piezoelectric crystal, dielectric resonator, etc. The inductance and capacitance of these is known. The change in the frequency, amplitude or phase of this oscillating circuit can be measured with different connections, where the system 10 under the measurement is connected in parallel or in bridge with a reference circuit 20, consisting of a reference capacitor 18 and a reference inductor or a resonator component 19. The radiation may then be defined by means of a control circuit 22, which may contain eg. a microprocessor. One readout electronics and a method, which can be used as a readout circuitry for radiation determination circuitry in accordance to the invention, has been presented more in detail in the article: H. Seppä, VTT Automation Technology Review 1995, "Resolution of the capacitive sensor", which is incorporated herein by reference.

Figure 6 presents a schematic overview of a realization of a compact radiation determination arrangement in accordance to the invention. In this the radiation detector 8 is installed on an insulating substrate 32, such as ceramics, glass etc. The substrate is patterned with a thin film technique, a thick film technique or other suitable technique, in order to provide the required electrical leads 17 for the electrical connections for the components and if necessary, the inductive component 9 in a close vicinity of the detector 8 on the same side of the substrate 32 as the detector is.

On the other side of the substrate plate 32 there is a metal plate or foil 34, or a corresponding electrically conductive

component. On the other side of said metal plate 34 there is another ceramic etc. insulating substrate plate 33. The reference circuit 20 of the oscillating circuit 10 is mounted onto the other side of this other substrate 33 in a similar manner to the circuit 10. The metal or other conductive plate 34 acts as an electrical shield between the detector circuit 10 and the reference circuit 20. The metal plate 34 or corresponding component acts also as a radiation shield so that the detector component 8 is exposed to radiation but the components on side of the reference circuit are not exposed to the radiation.

The system constructed in accordance with figure 6 is essentially compact. The length of the required leads and wiring can be minimized. Furthermore, it enables the thermal control in a environment, which is as similar as possible for both of the oscillating circuit 10 and the reference circuit 20. It is possible to implement cooling or other thermal controlling of the system by using the metal plate in the middle of the structure. This assures that the operation of both of the circuits is not affected by thermal effects, and thus the circuits are thermally stabilized. The system described here can be packaged into a standard type of a package, such as a TO-cans, etc., used in electronics industry.

It will be understood that the invention can be altered and modified from the description of the presented examples, and that the spirit and scope of the invention is defined by the appended claims, and is thus not intended to be limited by the previous examples.

Claims

1. A method for a determination of radiation, c h a r a c -
t e r i z e d in that it comprises connecting a radiation
detector as a part of a radiation sensitive oscillating
circuit for determining a change in the capacitance of the
radiation detector induced by the radiation.
2. A method according to claim 1, c h a r a c t e r i z e d
in that it comprises measuring of the change of frequency,
amplitude or phase of said oscillating circuit.
3. A method according to claim 1 or 2, c h a r a c t e r i -
z e d in that the radiation detector is provided from a
semiconductor material.
4. A method according to any of claims 1 - 3, c h a r a c -
t e r i z e d in that it includes a step of determining the
radiation by means of a reference oscillating circuit which is
connected in parallel or in bridge with said radiation sensi-
tive circuit and not exposed to the radiation.
5. A method according to any of claims 1 - 4, c h a r a c -
t e r i z e d in that it comprises steps for tuning the
capacitance to be measured by an inductance and measuring the
impedance change of the oscillating circuit.
6. A method according to any of claims 1 - 4, c h a r a c -
t e r i z e d in that it comprises steps for connecting the
capacitance to be measured as a part of a radiation sensitive
oscillator circuit, and detecting the change of the frequency,
amplitude or phase from this circuit.
7. An apparatus for determining radiation, c h a r a c t e -
r i z e d by comprising
a radiation sensitive oscillating circuit (10), which
includes a radiation detector component (8) and a resonating
component (11) or an inductive component (9),

wherein the oscillating circuit (10) is arranged to detect the change of the capacitance of the radiation detector component (8) induced by radiation (1).

8. An apparatus according to claim 7, characterized in that it further comprises means for measuring the frequency, amplitude or phase of the resonance of the oscillating circuit (10).

9. An apparatus according to claims 7 or 8, characterized in that the radiation detector component (8) comprises semiconductor material.

10. An apparatus according to claim 9, characterized in that the semiconductor radiation detector component (8) comprises a substrate (6) and pn-junctions (4,5) provided thereon, a power supply and a resetting circuit (16).

11. An apparatus according to claim 9, characterized in that the semiconductor radiation detector component (8) comprises a passivation layer (3) provided on the surface of the semiconductor substrate and metal contacts (7) provided on the surface of the passivation layer (3), which are arranged to influence the electric field inside the semiconductor substrate by means of voltage applied to the contacts.

12. An apparatus according to any of claims 7 - 11, characterized in that the resonator component (11) comprises a piezoelectric crystal or a dielectric resonator or some other type of a resonator component used in radio frequency or microwave electronics.

13. An arrangement for determination of radiation, characterized by comprising

a radiation sensitive oscillating circuit (10), which includes a radiation detector component (8) and a resonator component (11) or an inductor component (9), said circuit (10)

being arranged to detect changes in the capacitance of the radiation detector component (8) induced by radiation (1), and a reference circuit (20) connected in parallel or in bridge with the radiation sensitive circuit (10), said reference circuit including a reference capacitance (18) and a resonator (11) or an inductor (9) component in a corresponding manner to the radiation sensitive oscillating circuit (10).

14. An arrangement according to claim 13, c h a r a c t e - r i z e d by further comprising

a substrate (32), onto which said oscillating circuit (10) is provided,

another substrate (33), onto which said reference circuit (20) is provided, and

an electrically conductive isolation plate (34), which is placed between said substrate (32) and another substrate (33),

the arrangement being such that radiation sensitive oscillating circuit (10) and the reference circuit (20) are provided on the opposite surfaces of the assembly.

15. A system according to claims 13 and 14, c h a r a c t e - r i z e d by further comprising means (22) for determining the radiation from differences between the frequency, amplitude or phase of said radiation sensitive circuit (10) and said reference circuit (20).

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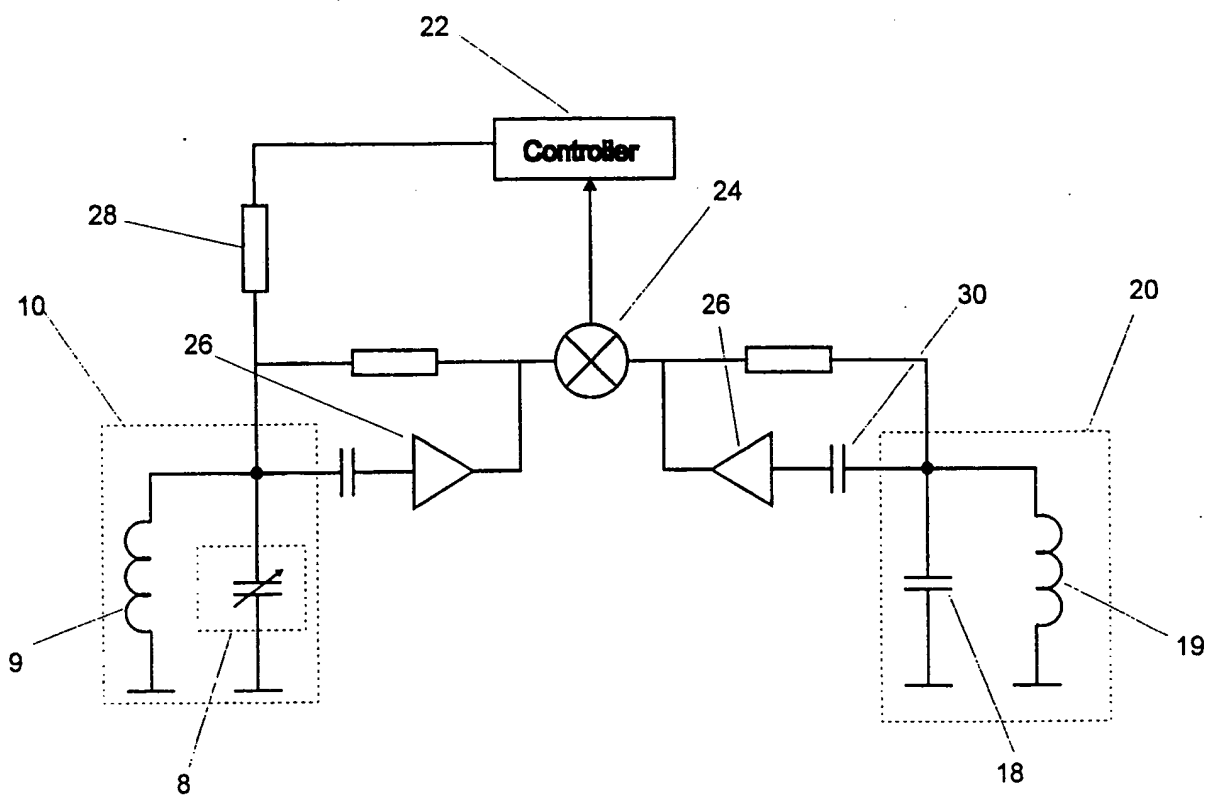


Fig. 1

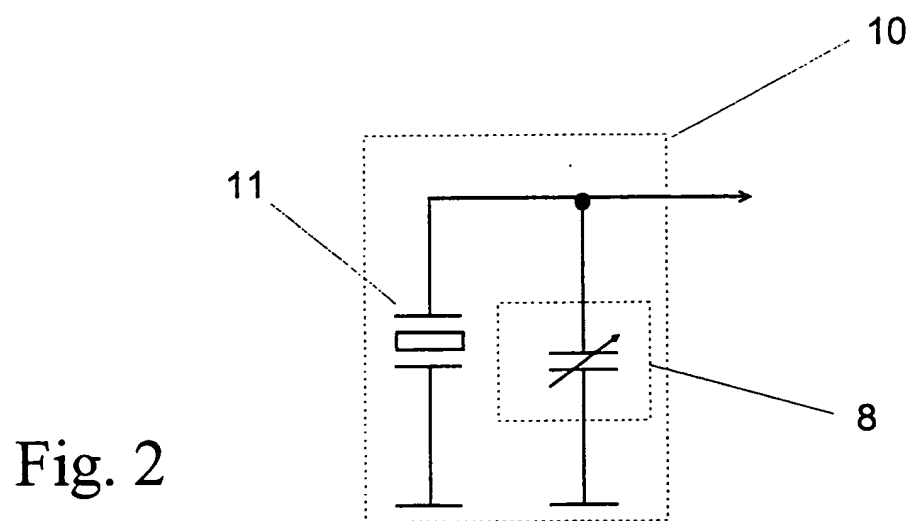
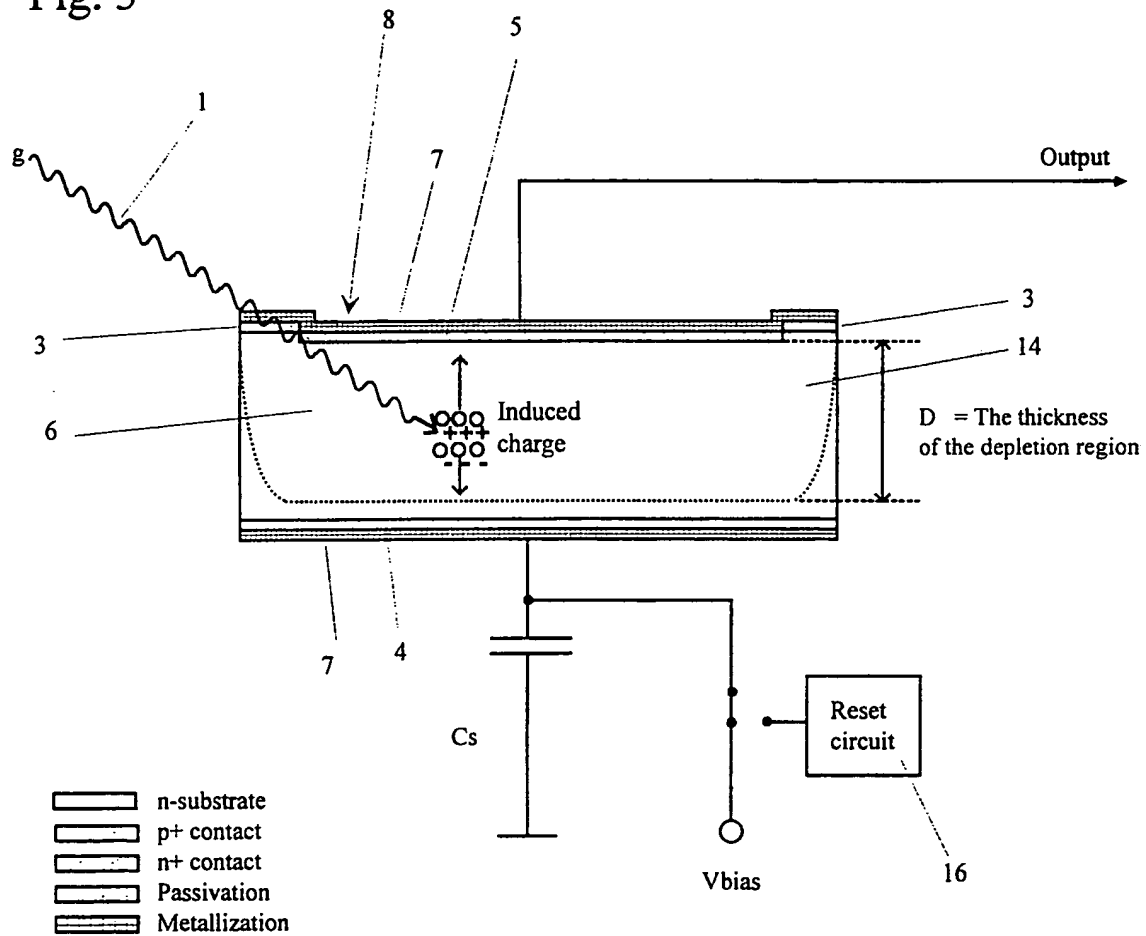


Fig. 2

Fig. 3



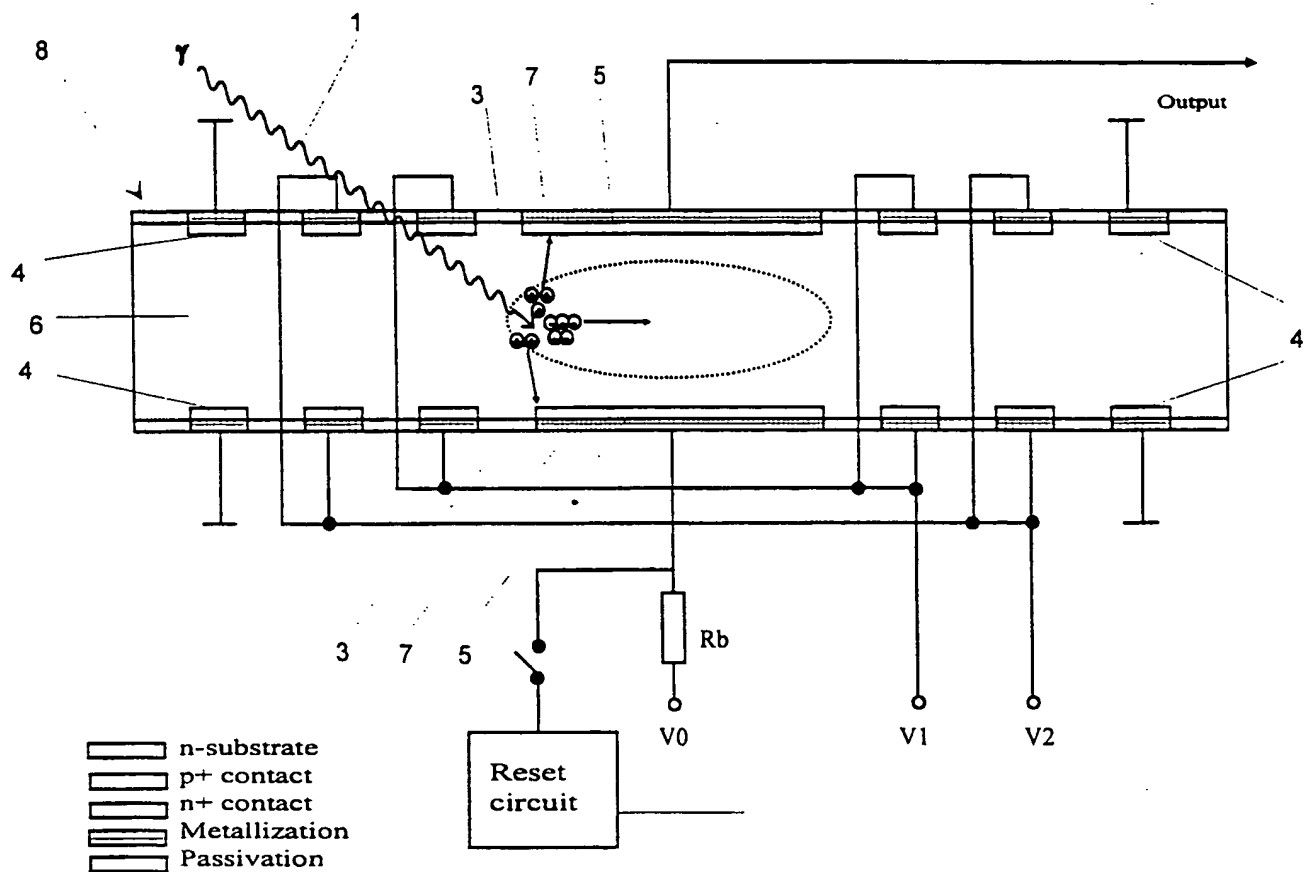


Fig. 4

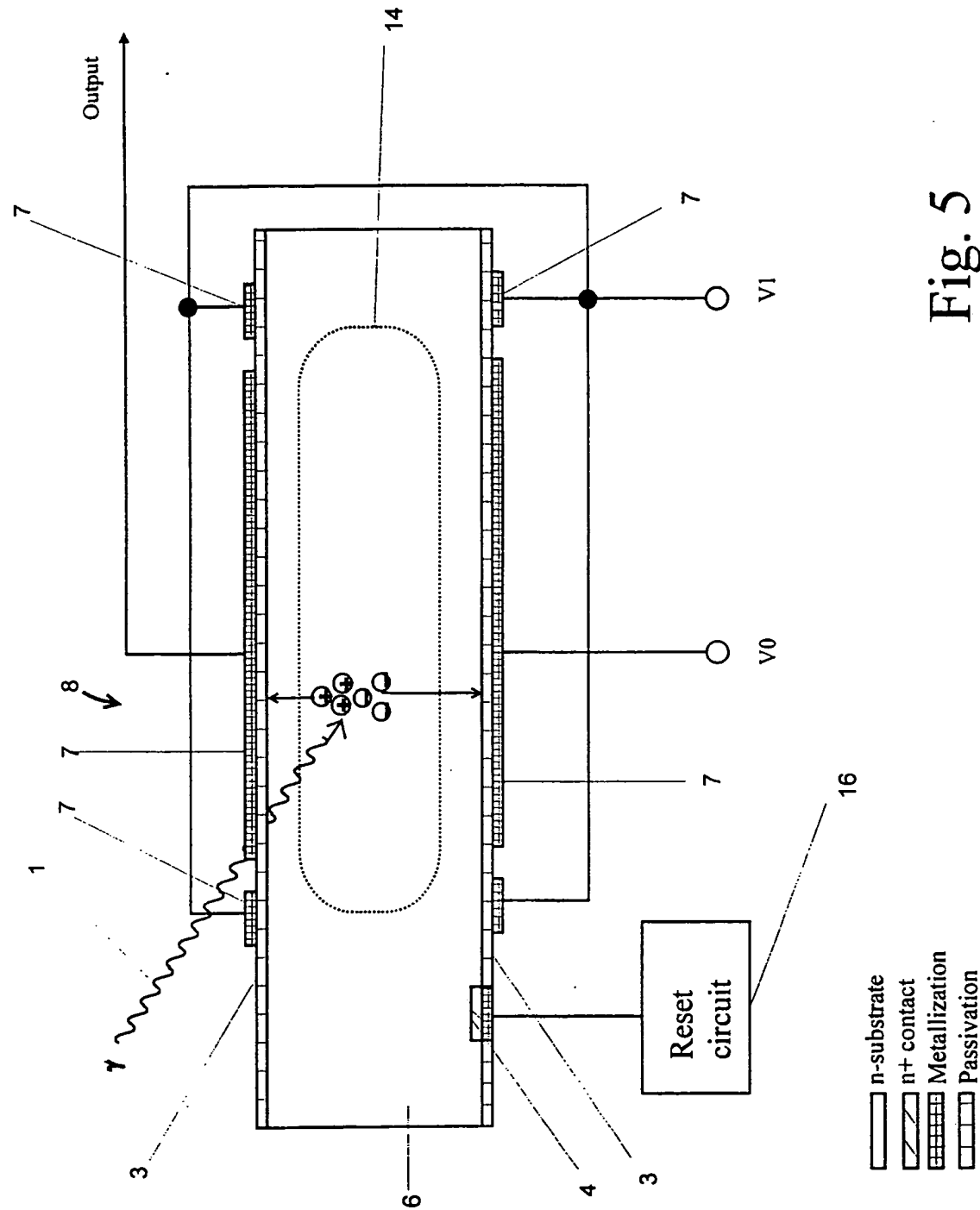


Fig. 5

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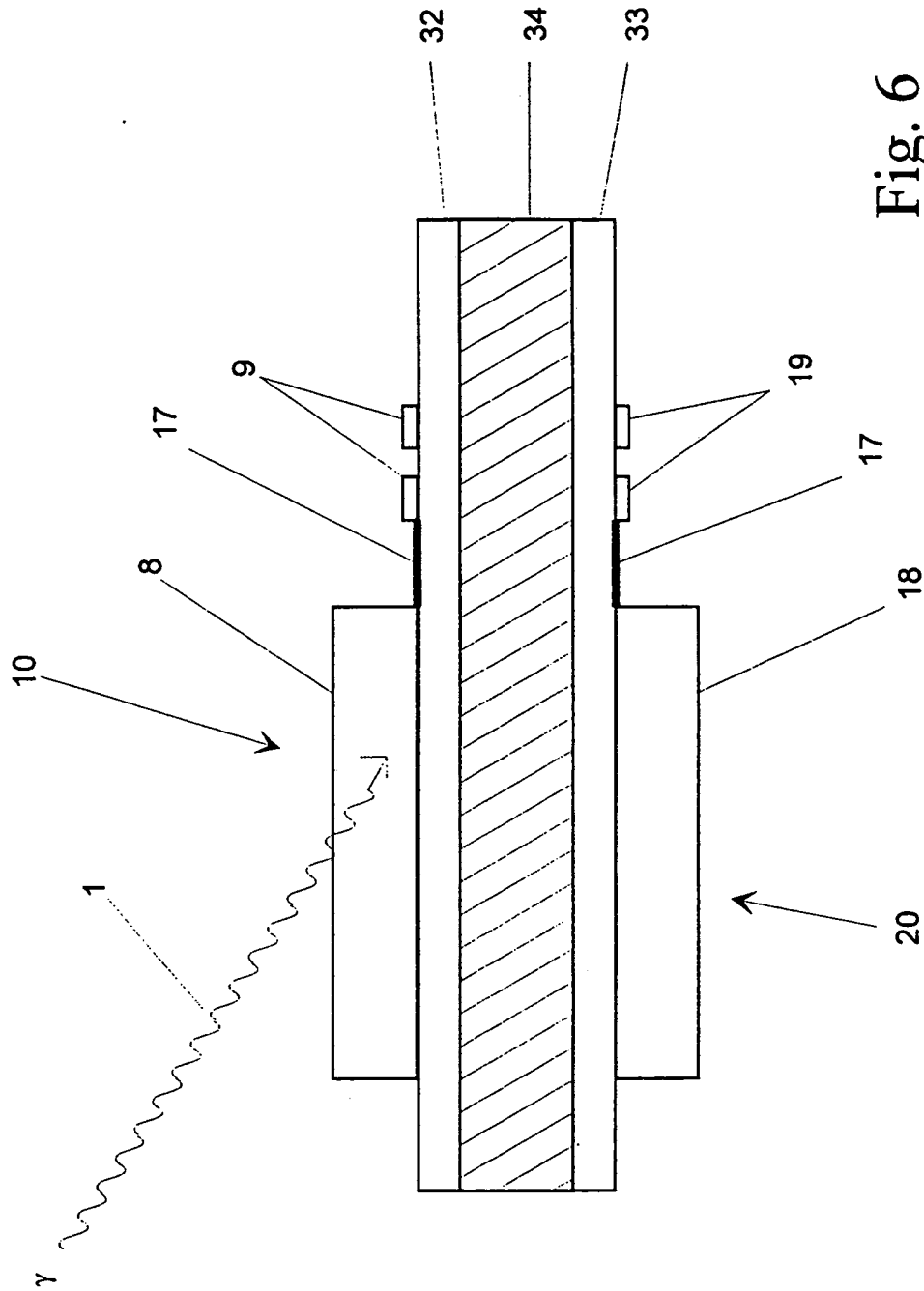


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI 98/00153

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G01T 1/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: G01T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5407276 A (BARBARA L. JONES), 18 April 1995 (18.04.95), column 2, line 13 - line 17, claims 10,11, abstract	1-3,5-15
A	--	4
X	US 5559332 A (EDWARD G. MEISSNER ET AL), 24 Sept 1996 (24.09.96), column 3, line 16 - line 24	1-3,5-15
A	--	4
A	US 5336890 A (HIROSHI KITAGUCHI ET AL), 9 August 1994 (09.08.94), cited in the application	1-13

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search

20 July 1998

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21 -07- 1998

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